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GB A 2063747 GB 1301987 GB 1097456
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(58) Field of search
F1V
B3R

(54) Hollow blade

(57) A hollow blade composite blade is disclosed. A corrugated core sheet is disposed between two sheathing members to form a blade airfoil. The blade is formed by diffusion bonding the core sheet to the sheathing members and shaping by superplastic forming. The blade is stiffened by fibrous composite material in at least one sheathing member, and it resists foreign object damage by strategic use of titanium.

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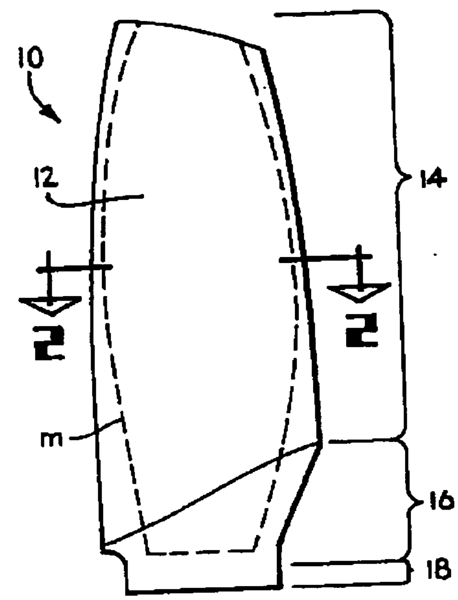

Fig 1

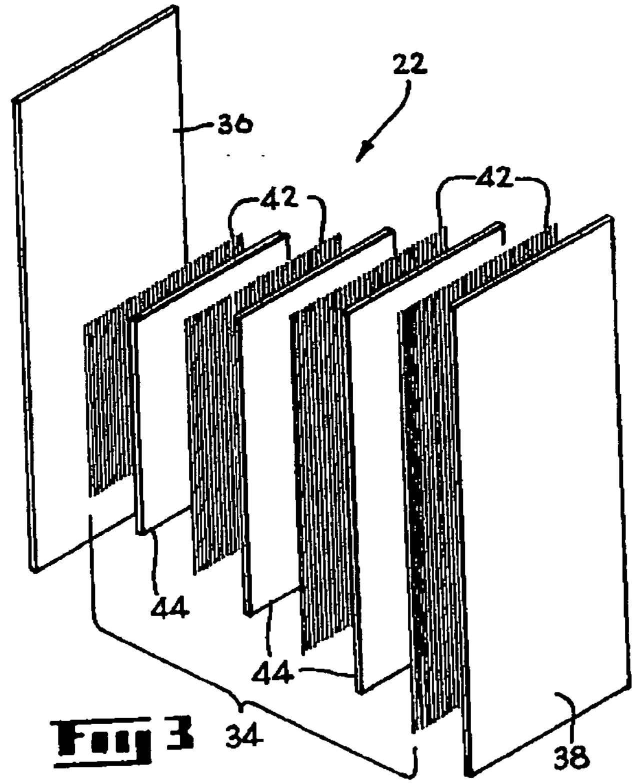

Fig 3

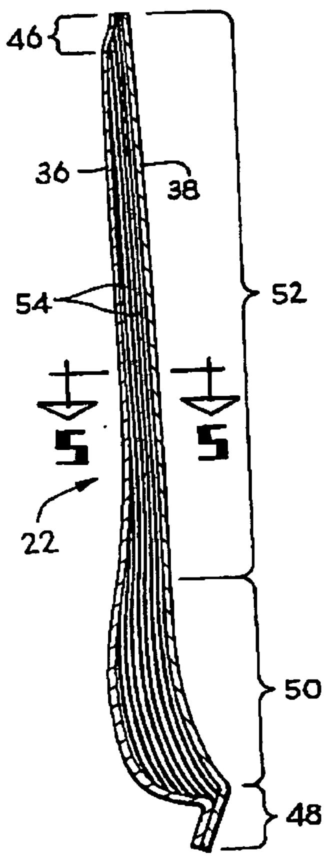

Fig 4

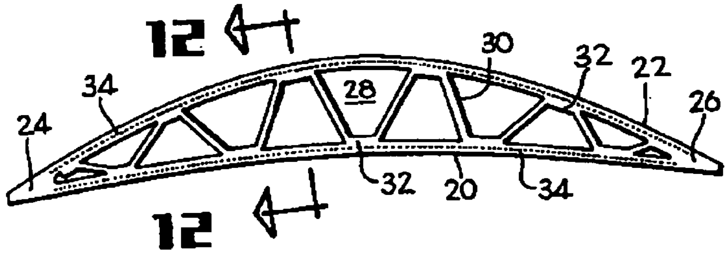

Fig 2

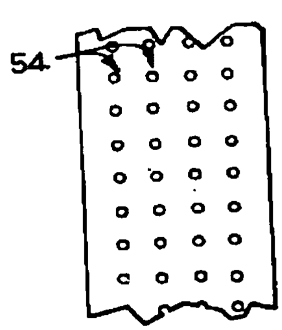

Fig 5

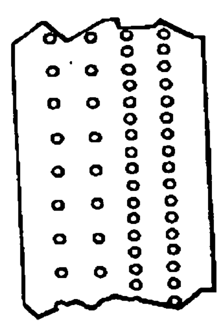

Fig 6

SPECIFICATION

Hollow blade

Turbomachinery blades, such as are used in a fan or compressor stage of a modern jet engine, must meet a number of demanding design requirements. For example, light weight is essential so as to permit higher tip speeds, lighter weight rotors and reduced radius ratio designs. Blade stiffness is required to prevent excessive vibration while high strength is needed to minimize foreign object damage. In addition, to be commercially useful, a blade must be of reasonable cost to manufacture.

Hollow blades have been used in the past to reduce weight. Such blades may be fabricated by braze bonding sheathing members to a stiffening core. For example, Clark U.S. Patent 3,095,180 shows a hollow blade made by this method. In general, braze bonds tend to be weaker than the surrounding material. Hollow blades may be alternately fabricated by machining channels on the mating surfaces of airfoil sections and then diffusion bonding the sections together. Although generally stronger than a brazed core blade, such blades require costly precision fixturing to align the channels and even small deviations in alignment result in stress concentrations.

Blade stiffness may be achieved by combining different high stiffness materials into a composite blade. Improved tensile strength and stiffness may be realized by integrating fibrous material into the blade airfoil. For example, Seiwert U.S. Patent No. 3,572,971 discloses the use of thin fibers in a central blade core. A problem encountered with solid composite blades is that they tend to be heavy and expensive to produce due to the amount of material required for their fabrication.

Hollow composite compressor blades with fibers bonded integrally to an aluminum matrix are shown in Stargardter, U.S. Patent No. 3,981,616. The problem with such blades is that they exhibit poor resistance to foreign object damage.

It is an object of the present invention to provide a new and improved turbomachinery blade.

According to the invention there is provided a blade comprising:

a hollow airfoil with a core disposed therein, said core being diffusion bonded to said airfoil.

The blade to be described hereinafter by way of example is of enhanced stiffness, eliminates the need for midspan shrouds, and has increased resistance to foreign object damage. The blade has a variable width core and variable width sheathing, with enhanced strength in the root.

In a more specific form of the present invention a rotor blade with a hollow airfoil including a tip portion, leading edge and trailing edge is disclosed. The airfoil is formed by first and second sheathing members surrounding a core region which is diffusion bonded to the first and second members. The rotor blade further includes a shank and a root. The sheathing members extend from the tip portion to the shank and the root to form a part of the shank and root.

In the drawings:–

Figure 1 is a view of a turbomachinery blade in accordance with one form of the present invention.

Figure 2 is a cross-sectional view of the blade shown in Fig. 1 taken along the line 2–2.

Figure 3 is an exploded view in perspective of the laminates which form a sheathing member according to one form of the present invention.

Figure 4 is a cross-sectional side view of a sheathing member according to one form of the present invention.

Figure 5 is a sectional view of the sheathing member of Fig. 4 taken along the line 4–4.

Figure 6 is a similar view to that shown in Fig. 5 according to an alternate form of the present invention.

Figure 7 is an exploded view or perspective of one stage in the fabrication of the blade shown in Fig. 1.

Figure 8 is a cross-sectional view of a mold for forming the blade in Fig. 1.

Figure 9 illustrates the process whereby the blade in Fig. 1 is formed in the mold of Fig. 8.

Figure 10 shows a view of a core prior to bonding according to an alternative form of the invention.

Figure 11 shows a view of a core prior to bonding according to yet another form of the invention.

Figure 12 is a cross-sectional view of the blade of Fig. 2 taken along the line 12–12.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows a hollow blade 10 according to one form of the present invention viewed from its pressure side 12. The contour of a core region 28, for example as shown in Fig. 2, is outlined by phantom line m. Blade 10 includes airfoil 14, shank 16 and root 18.

Fig. 2 shows a cross-sectional view of hollow blade 10 taken along line 2–2 in Fig. 1. Pressure side sheathing member 20 and suction side sheathing member 22 are joined by diffusion bonding to form leading edge 24 and trailing edge 26. The sheathing members 20 and 22 surround a core region 28 containing a core in the form of a corrugated core sheet 30. Sheathing members 20 and 22 are diffusion bonded to corrugated core sheet 30

at peaks 32 by a process discussed in more detail hereinafter. Contained within each sheathing member 20 and 22 is a reinforcement sheet 34 of a plurality of plies of a fibrous composite material, shown in more detail in Fig. 3. In order to reduce foreign object damage reinforcement sheet 34 does not extend into leading edge 24 or trailing edge 26. Rather, these regions generally include nonfibrous material with good impact resistance, as for example titanium.

The sequence of steps according to a preferred means of fabricating blade 10 is shown in Figs. 3, 7, 8 and 9. Fig. 3 shows, in perspective, an orientation of laminates which forms sheathing members 20 or 22 for a blade according to one form of the invention. Face sheets 36 and 38 are positioned on opposite sides of fibrous composite assemblage 34. Assemblage 34 includes alternate laminates of metal sheets 42 and fiber sheets 44. These laminates are of varying heights so that, as for example shown in Fig. 4, more fibers are positioned at the shank region 50 of sheathing member 22 than at the tip portion 46 of airfoil region 52. The fibers extend into and generally decrease throughout root portion 48.

In a preferred embodiment of the present invention, shown in Fig. 3, face sheets 36 and 38 are made of titanium with a thickness of about 15 mils. Fiber sheets 44 may be formed by suspending any suitable fiber, as for example silicon carbide coated carbon filaments, in a polymeric binder. Alternating with fiber sheets 44 are metal sheets 42 of about 5 mil thick titanium. After these sheets are properly aligned they are subjected to sufficient temperature and pressure, as is well known in the art, to diffusion bond the sheets to form sheathing member 22. During this process the binder material burns off and the metal migrates to fill the voids left by the binder. This results in fibrous plies 54, as shown in Fig. 4, being embedded in a metal matrix and contained between face sheets 38 and 38.

A view of the plies taken along the line 5–5 in Fig. 4 is shown in Fig. 5. The density of fibers in sheathing member 22 is shown in Fig. 5 to be generally uniform. Fig. 6 shows an alternative embodiment wherein the density of fibers has been varied to provide design flexibility in achieving impact resistance in some regions of the blade while maintaining high stiffness in other regions. It will be clear to a person skilled in the art that many arrangements of fibers are possible. It should also be noted that in the process of forming sheathing member 22 it is possible to roughly preform member 22 by means of a mold press to its cambered, twisted final shape. In addition, it may be desirable to leave fibers out of sheathing member 20 or 22 depending upon design requirements.

Figs. 7–9 illustrate a process for diffusion bonding core sheet 30 to sheathing members 20 and 22 using gas pressure in a mold cavity. Fig. 7 shows a perspective view of core sheet 30 sandwiched between sheathing members 20 and 22 which have been fabricated as described above. A plug member 56, of for example titanium, is positioned at one end of blade assemblage 60 to form the blade root. Prior to bonding these members together, core 30 is coated on two sides in a strip-like pattern 58 with a substance such as boron nitride which prevents diffusion bonding with subsequently applied materials. Assemblage 60 is next placed in a mold 62, as shown in Fig. 8. Gas is introduced through tube 63 at sufficient temperature and pressure to diffusion bond assemblage 60 together.

Blade 10 is formed by superplastic forming, as shown in Fig. 9. Gas is introduced between sheathing members 20 and 22 through a tube 64 at sufficient temperature and pressure to force members 20 and 22 apart thereby forming core region 28 and simultaneously stretching core members 66. As noted above, core sheet 30 bonds to sheathing members 20 and 22 only at the non-treated regions of sheet 30 thereby forming corrugations.

This process of diffusion bonding and superplastic forming is described in more detail in Hamilton, U.S. Patent No. 3,927,817, the disclosure of which is incorporated herein by reference. Corrugated core sheet 30, thus formed, is diffusion bonded so sheathing members 20 and 22 at peaks 32. These joints exhibit exceptional strength far in excess of those in prior art blades. It should be clear that core geometry depends on the configuration of pattern 58 of boron nitride or other diffusion bond inhibiting material.

Figs. 10 and 11 show alternative core pattern configurations. For example, Fig. 10 shows a dot pattern which yields a post core and Fig. 11 shows a zig-zag pattern which yields a zeta core However, the invention is not limited to the above-stated patterns but includes any pattern which yields a useful core. Typically, such cores will include a plurality of core members connnecting sheathing members 20 and 22. For example, as shown in Fig. 9, core 30 includes core members 66. In contrast, the core generated by the dot pattern of Fig. 10 will include core members in the form of posts.

A cross section of blade 10 viewed from the leading edge and taken along the cut 12–12 in Fig. 2 is shown in Fig. 12. Corrugated core sheet 30 is shown between pressure side sheathing member 20 and suction side sheathing member 22. Core region 28 is partially closed off at tip portion 46 and shank 16 by core sheet 30 being bent over and bonded to sheathing member 20 or 22. Complete close off is achieved by bonding tip close off strip 76 to sheathing members 20

and 22. Various configurations for tip portion 46 are possible. In the embodiment shown, tip portion 46 has a depression 68. Alternatively, depression 68 may be filled with a lightweight material or sheathing member 26 may be machined down to form a squealer tip. Core region 28 extends into shank 16, as shown, and is separated from plug member 56 by core sheet 30. Sheathing member 20 includes a reinforcement sheet 74 of at least one ply of fibrous composite material as described in more detail above with reference to Fig. 4.

The arrangement and number of plies of fibrous composite material may vary. In the embodiment shown in Fig. 12, the number of plies within reinforcement sheet 74 is greater at shank 18 than near tip portion 46 and generally decreases throughout root 18. The plies flair out at root 18 and generally lie near the outer surface of root 18. Reinforcement sheet 74 is in laminar contact with inner face sheet 36 and outer face sheet 38 of nonfibrous material, as described in more detail with reference to Fig. 4. Tip portion 46 consists essentially of nonfibrous material such as titanium for increased resistance to foreign object damage. In a like manner, a reinforcement sheet 74 and face sheets 36 and 38 comprise sheathing member 22. One function of reinforcement sheet 74 is to improve blade stiffness. Under certain design conditions it may be desirable to omit the reinforcement sheet from one or both sheathing members. Such configurations are within the scope of the present invention.

The blade as described herein has a core region of variable cross-sectional area. Referring again to Fig. 12, core region 28 generally decreases in cross-sectional area from the shank to tip portion 46. Thus, the cross-sectional area of core region 28 near tip portion46 is less than the cross-sectional area of the core region near the shank.

The reinforced titanium blade described and illustrated herein has the qualities of light weight, high stiffness, high strength, and high foreign object damage resistance. When fan blades are produced according to the process described herein, the high stiffness/high strengh characteristic permits the elimination of midspan and/or tip shroud, the reduction of blade radius ratio, and the increase of blade tip speed. Thus, the blade according to the invention is capable of improved operation of those heretofore known.

It will be clear to those skilled in the art that the present invention is not limited to the specific embodiments described and illustrated herein. The invention applies to any hollow blade with core diffusion bonded therein. It is also possible to vary materials and fiber location to suit particular design requirements.

It will be understood that the dimensions and the proportional and structural relationships shown in the drawings are illustrated by way of example only and that these illustrations are not to be taken as the actual dimensions or proportional structural relationships used in the blade of the present invention.

CLAIMS

1. A blade comprising:
a hollow airfoil with a core disposed therein, said core being diffusion bonded to said airfoil.

2. A blade, as recited in claim 1, wherein said airfoil is formed by first and second sheathing members and wherein said core comprises a plurality of core members connecting said first and second sheathing members.

3. A blade, as recited in claim 1, wherein said core comprises a corrugated sheet.

4. A rotor blade comprising:
a hollow airfoil including tip portion, leading edge, and trailing edge; said airfoil being formed by first and second sheathing members surrounding a core region containing a core, said core being diffusion bonded to said first and second members;
a shank; and
a root;
wherein said sheathing members extend from said tip portion to said shank and said root to form a part of said shank and root.

5. A blade, as recited in claim 4, wherein said core comprises a corrugated sheet.

6. A blade, as recited in claim 4, wherein the thickness of each of said sheathing members is greater at said shank than at said tip portion of said airfoil.

7. A blade, as recited in claim 4, wherein at least one of said sheathing members comprises a reinforcement sheet of at least one ply of fibrous composite material.

8. A blade, as recited in claim 7, wherein said sheathing member comprising said reinforcement sheet further comprises inner and outer sheets of nonfibrous material in laminar contact with said reinforcement sheet.

9. A blade, as recited in claim 8, wherein said fibrous composite material includes silicon carbide coated carbon filament within a titanium matrix; and wherein said nonfibrous material includes titanium.

10. A blade, as recited in claim 8, wherein the number of said plies within said reinforcement sheet is greater at said shank than near said tip portion and generally decreases throughout said root.

11. A blade, as recited in claim 10, wherein said plies lie generally near the outer surface of said root.

12. A blade, as recited in claim 8, wherein said tip portion, leading edge, and trailing edge consist essentially of nonfibrous material.

13. A blade, as recited in claim 4,

wherein said core region extends into said shank and wherein the cross-sectional area of said core region near said tip portion is less than the cross-sectional area of said core region near said shank.

14. A blade substantially as hereinbefore described with reference to and as illustrated in any figure of the drawings.

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